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AN EMPIRICAL SHAPED CHARGE JET BREAKUP MODEL

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14. ABSTRACT

Much of the increase in penetration capability of copper lined shaped charges has been due to changes that increased copper jet breakup time. This has been accomplished largely independent of the growing understanding of breakup phenomenology. This report discusses an empirical shaped charge jet breakup model and provides significant experimental confirmation over a broad range of velocity gradients. Analysis using this model has proved to be useful in order to explain observed performance and to identify undesirable characteristics.

15. SUBJECT TERMS
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INTRODUCTION

The parameters that affect jet length and breakup times are fairly well known, but there is some controversy over the exact nature of the dependencies. Walsh, J.M. (1984), theorized that the dependence of jet length would take a particular form based on his determination of a dimensionless parameter for the problem and numerical experiments in which initial perturbation strengths were varied (ref. 1). Walsh did not present comparisons with experimental results. Chou, P.C. (1986), has presented a variety of different jet breakup models with some data comparisons (ref. 2). Mostert, F.J. (1995), has suggested that breakup time is proportional to $\left(\frac{\Delta m}{\Delta v}\right)^{1/3}$ where *m* is the accumulated jet mass and *v* is the jet velocity associated with the final accumulated jet mass versus jet velocity characterization starting from the jet tip (ref. 3). The values of Δm and Δv are respectively the jet mass and the velocity difference of the portion of jet in question. For a typical shaped charge, $\frac{\Delta m}{\Delta v}$ is essentially invariant with respect to time after jet formation is complete. The parameter $\left(\frac{\Delta m}{\Delta v}\right)^{1/3}$ or $\left(\frac{dm}{dv}\right)^{1/3}$ is closely related to Walsh's dimensionless parameter.

BREAKUP FORMULATION

The analysis and data provided are for ductile jets, i.e., the radius at the neck goes to zero at failure. Walsh theorized that the final length *L*b of an element of stretching (elastic perfectly plastic) jet with initial length *L*0 should be given by (eq. 1)

$$L_b = L_0 \frac{u_x{}^{2/3} R^{2/3}}{\left(\sigma/\rho\right)^{1/3}}\left[\frac{C}{\phi^{0.05}\varphi^{0.22}}\right],\ \phi = \frac{\sigma/\rho}{u_x{}^2 R^2} \tag{1}$$

Where all parameters are defined at the moment of jet formation, ϕ is a dimensionless parameter, *ux* is velocity gradient, *R* is jet radius, σ and ρ are respectively jet strength and density and φ is a perturbation strength term. Walsh was led to this theory by dimensionless analysis and numerical simulations in which he investigated the effects of various types of perturbations and perturbation strengths. Walsh made no comparisons with experimental data. Let *L0* be a differential increment of jet length *dL0*, then $u_x = \frac{dv}{dL_0}$ where *dv* is the velocity difference across the increment.

Then (eq. 2)

$$\rho^{1/3} dL_0 u_x{}^{2/3} R^{2/3} = \left(\rho R^2 dL_0\right)^{1/3} dv^{2/3} = \left(\frac{dm^*}{dv}\right)^{1/3} dv \text{, where } dm^* = \frac{dm}{\pi} = \rho R^2 dL_0 \tag{2}$$

Finally (eq. 3)

$$dL_b = \frac{1}{\sigma^{1/3}}\left(\frac{dm^*}{dv}\right)^{1/3} dv\left[\frac{C}{\phi^{0.05}\varphi^{0.22}}\right] \tag{3}$$

In the virtual origin approximation (Chou) *dLb=tbdv.*

Hence (eq. 4)

$$t_b = \frac{1}{\sigma^{1/3}}\left(\frac{dm^*}{dv}\right)^{1/3}\left[\frac{C}{\phi^{0.05}\varphi^{0.22}}\right] \tag{4}$$

This equation can be rearranged into a form in which the quantities that can be measured or estimated, *tb* and $\frac{dm^*}{dv}$ are separate from those that cannot be measured or estimated.

EMPIRICALLY-BASED JET BREAKUP MODEL

The resultant jet breakup formulation is (eq. 5)

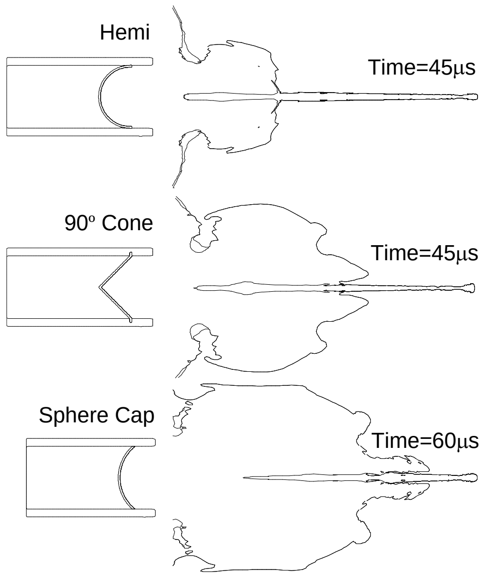
$$Q = \frac{t_b}{\left(\frac{dm^*}{dv}\right)^{1/3}} = \frac{1}{\sigma^{1/3}}\left[\frac{C}{\phi^{0.05}\varphi^{0.22}}\right] \tag{5}$$

For convenience, this ratio will be referred to as *Q*, the ductility factor, and is treated as an empirically determined material parameter. As the quantity $\frac{dm^*}{dv}$ is essentially invariant after jet breakup, it can be determined from x-rays of particulated jets or estimated from numerical simulations of shaped charge collapse and jet formation. Table 1 presents reduced data from jet x-rays and numerical simulations. Figure 1 presents some shaped charge numerical simulations used for the data analysis. Figure 2 presents resultant plots comparing the reduced data to various levels of *Q*, the ductility factor.

Table 1

t_b/D versus $\frac{1}{D}\left(\frac{dm^*}{dv}\right)^{1/3}$

Device	tb from	tb/D (μs/mm)	dm^*/dv from	$\frac{1}{D}\left(\frac{dm^*}{dv}\right)^{1/3}$	$Q = t_b\Big/\left(\frac{dm^*}{dv}\right)^{1/3}$	$\frac{Q}{60}$	$\frac{Q_{slow}}{Q_{fast}}$
81.3mm Cu cone	$\frac{dL_b}{dv}$	2.07 slow 1.75 fast	$\frac{1}{\pi}\frac{dm}{dv}$	0.347 0.300	59.7 58.3	0.995 0.97	1.03
38.1mm Cu hemi	$\frac{L_b}{\Delta v}$	3.09	$\frac{\rho L_b R^2}{\Delta v}$	0.575	53.7	0.90	
38.1mm Cu 90° cone	$\frac{L_b}{\Delta v}$	1.38	$\frac{\rho L_b R^2}{\Delta v}$	.409	33.7	0.56	
38.1mm Cu spherical cap	$\frac{L_b}{\Delta v}$	2.44	$\frac{\rho L_b R^2}{\Delta v}$	.696	35.1	0.58	
76.2mm Cu hemi	$\frac{dL_b}{dv}$	2.18 slow 1.78 fast	$\frac{1}{\pi}\frac{dm}{dv}$	0.690 0.547	31.6 32.5	0.53 0.54	0.97
140mm Cu trun. cone	$\frac{L_b}{\Delta v}$	2.73	$\frac{\rho L_b R^2}{\Delta v}$	0.473	57.7	0.96	
150mm Cu trumpet	$\frac{L_b}{\Delta v}$	2.33 slow 1.80 mid 1.13 fast	$\frac{\rho L_b R^2}{\Delta v}$	0.35 0.309 0.20	66.6 58.3 58.3	1.11 0.97 0.97	1.14
150mm Cu Free form	tb	1.39 tail 0.267 tip	$\rho t_b R^2$	0.195 0.097	71.3 27.5	1.19 0.46	2.59



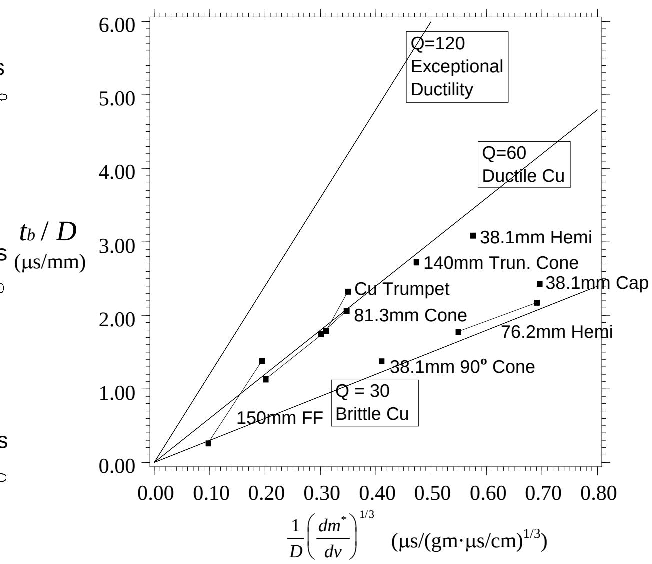


Figure 1
ALE modeling of shaped charges for jet characterization. Studies. Dislocation percolating on (111) plane with SFT's

Figure 2
Ductility factor data for various copper shaped charges

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